DREDGE TAILINGS ON THE RED RIVER NARROWS CHANNEL RESTORATION PROJECT: WEED SITES AND THE EFFECTIVENESS OF RESTORATIONS

by

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in

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GLOSSARY

Invasive species: Species that establishes, persists, and spreads widely in natural ecosystems outside the plant's native range (Menalled, 2017).

Noxious species: Any plant considered injurious to public health, agriculture, recreation, or property as designated by federal, state, or local government (Menalled, 2017).

Substrate: A substance or surface that an organism grows and lives on and is supported by (Cambridge Dictionary, 2025).

ABSTRACT

The success of river restoration is contingent on revegetation to stabilize river banks, yet few restoration projects complete any kind of long-term monitoring. Common challenges at river restoration projects include mining dredge tailings which create challenges for the establishment and retention of healthy, native plant populations. These challenges are evident within the Red River Narrows channel restoration project near Elk City, Idaho, where leveling or removal of all the dredge tailings was not completed between 2008 and 2012. These restoration methods have resulted in an environment with inadequate conditions for native species to reestablish due to the presence of bare tailing materials, exposed substrate from tailing removal, and potential mineral leaching in the area, allowing invasive species to establish and persist. Therefore, I used GIS and remote sensing techniques to assess various vegetation changes within the Red River Narrows restoration project area between 1984 and 2023. I used unsupervised classification to estimate overlap between areas dominated by invasive species, such as spotted knapweed (*Centaurea maculosa* auct. non Lam.) and yellow toadflax (*Linaria vulgaris* Mill.), and those with dredge tailings and exposed substrate and completed a change detection analysis to demonstrate vegetation changes pre- and post-restoration. I also discuss broader implications for restoration planning and completion, long-term monitoring, invasive species, and herbicide treatments. My results indicate there are more weed species in areas with dredge tailings and exposed substrate, and vegetation changes pre- and post-restoration have only recently begun to return to pre-restoration levels of vegetation health, as measured by NDVI. My study echoes the importance of other restoration literature and the importance of long-term monitoring, given that revegetation is crucial to determine restoration success. Future development of remote sensing techniques to measure how a restoration project is progressing may be an essential part of future restorations, considering the lack of long-term monitoring in nearly all ecological restorations.

CHAPTER ONE

INTRODUCTION

Ecological restoration is a common and constantly evolving strategy to combat biodiversity loss, anthropogenic-caused environmental degradation, and climate change (Fischer et al., 2021, Suding, 2011). Restoration projects occur over a vast variety of ecosystems, including farmland, forests, wetlands, freshwater systems, and grasslands. Forest restorations have used fire to mimic natural disturbance regimes, though other methods such as cutting and reseeding/planting after a disturbance are frequently used (Wilcox, 2017, Xiao et al., 2015). Grassland restorations frequently use prescribed burning similarly to forest restorations, and their methods also include prescribed grazing and early successional habitat management to mitigate invasive annual grasses (Funk, 2021). Freshwater system restorations, such as river systems, frequently complete revegetation and river channel reconfiguration, which can be very involved and costly (Logar et al., 2019).

Regardless of restoration type, monitoring of ecological restorations is a tool that is commonly used to assess restoration success and efficacy, though there are no overarching monitoring standards or methods. Monitoring criteria can range from grassland restorations which use the Natural Community Health Index (Leahy & Buchanan, 2022) to the Stream Visual Assessment Protocol used for river channel restorations (USDA, 1998). The time frame of restoration monitoring is project dependent and there does not seem to be a standardized method in the United States, even for federal agencies such as the USDA (Yochum, 2018) and EPA (EPA, 2024). Determining the efficacy of restorations depends on the project's goals, and many

restoration projects do not create quantifiable performance standards to measure via monitoring (Association of State Wetland Managers, 2016).

Ecological restoration is common in private and government sectors, yet it often lacks adequate long-term monitoring to truly assess the success of restoration (Paolinelli Reis et al., 2024, Lindenmayer, 2020). Focusing on river and wetland restorations, the recovery of wetland areas to ideal ecosystem health conditions frequently took much longer than the typical monitoring phase of a restoration which is between 3 to 5 years (Matthews et al., 2009, Association of State Wetland Managers, 2016). Another example of this level of restoration monitoring is depicted by the National River Restoration Science Synthesis project, where less than half of all river restoration projects set measurable objectives and obtained quantitative monitoring data to evaluate restoration success (Bernhardt et al., 2007). Bernhardt et al. (2007) conducted telephone interviews with 317 restoration project managers, and the vast majority cited the lack of funds as the reason why more than half of the projects were not monitored after the restoration was completed. Interestingly, projects conducted in the central and southern United States were more likely to complete river restoration monitoring (>20% of projects) and that the projects with higher costs (>$1.5 million) were more likely to be monitored (Bernhardt et al., 2005).

River channel restoration projects typically do not complete long-term monitoring of the restoration area (Buchanan et al., 2014), and instead rely on a brief moment after the restoration is finalized to tell the story of a project's performance. When long-term monitoring of river restorations has occurred, the importance of riparian vegetation along river edges and banks in maintaining channel stability is stressed (Buchanan et al., 2014; Buchanan et al., 2012; Rosgen, 1994). Channel stability is also highly dependent on the establishment of healthy riparian

vegetation and is the only self-sustaining solution for channel stability (Buchanan et al., 2014; Buchanan et al., 2012; Rosgen, 1994). Once densely rooted riparian vegetation (i.e., willows, grasses, young tree saplings) establishes on banks, the features of low bank stability such as slope failure, active erosion, and channel widening are greatly minimized, even during flooding events (Buchanan et al., 2012, 2014). Buchanan et al. (2012, 2014) suggest using soil bioengineering practices, such as brush mattresses which are layers of live branches held together by stakes or wire (Hoag & Fripp, 2002), to help stabilize new streambanks while vegetation establishes. Managing for healthy riparian vegetation also has a positive effect on the ecosystem by restoring the natural delivery of organic matter, which plays a large part in channel morphology and habitat formation (Montgomery & Buffington, 1998). The success of river restoration depends in large part on the success of retaining or reestablishing riparian vegetation, though confounding factors such as disturbance can limit this ability.

Restoration projects can create many disturbances via construction equipment, hauling of materials, and material movement (Thompson & Luthin, 2010, Miller et al., 2004). These disturbances then create gaps in plant communities, which are usually filled first by colonizing species. Typically, early successional species may facilitate the colonization and growth of later successional species (Connell & Slayter, 1977). This process is disrupted by noxious and invasive species that were there before the disturbance or were able to colonize the area created by the disturbance. A noxious weed is any plant considered injurious to public health, agriculture, recreation, or property as designated by federal, state, or local government (Menalled, 2017). Comparatively, an invasive species establishes, persists, and spreads widely in natural ecosystems outside the plant's native range (Menalled, 2017). Native species typically

have a difficult time competing with these invasive species, and the seed banks are quickly dominated by invasive species (Gioria & Pyšek, 2016).

Invasive species are one of the few barriers to wetland ecosystem recovery, and therefore succession, that does not weaken over time (Aronson & Galatowitsch, 2008). Examples of these challenging species in the western United States include spotted knapweed (*Centaurea maculosa* auct. non Lam.), yellow toadflax (*Linaria vulgaris* Mill.), and common mullein (*Verbascum thapsus* L.). Spotted knapweed is an invasive species frequently found in many habitats, including disturbed areas and healthy native ecosystems. Spotted knapweed is a perennial that increases surface water runoff and stream sedimentation while reducing soil water infiltration (Lacey et al., 1989). Past research demonstrates spotted knapweed's phytotoxic abilities from the production of catechin to give the species an advantage against others (Callaway et al., 2005), though this does not seem to be the case in more recent research. For example, Duke et al. (2009) reviewed available research on catechin acting as an allelopathic chemical and influencing interference with the growth of other plant species; catechin levels in soils where spotted knapweed had grown were orders of magnitude less than those that could cause minor growth effects in sensitive species. Spotted knapweed has a deep taproot that assists in obtaining water from deep soil during dry times of year (Jacobs, 2012). Invasive species managers struggle to manage spotted knapweed effectively using herbicides and other common management tools, as the seeds can survive in soils with no seed input for eight years (Davis et al., 1993).

Like spotted knapweed, yellow toadflax also poses management challenges due to its persistent root systems and adaptability to various environments. Yellow toadflax is a perennial that can be difficult to manage due to its tap root, rhizomatous root systems, and its ability to form discrete populations (Saner et al., 1995). Discrete populations of toadflax can grow quite

large and persist due to its deep root and perennial life cycle, particularly in areas with disturbances such as grazing or fire (Saner et al., 1995). Its tap root survives at least four years and can reach nearly a meter into the soil, surviving temperatures as low as -15 ºC (Jacobs & Sing, 2006). The invasiveness of yellow toadflax varies among ecosystems, with the most invasive populations existing on ridges followed by valleys and forests (Lehnhoff et al., 2008). This species was introduced in North America as an ornamental and is still sold by nurseries and seed companies (Jacobs & Sing, 2006). Yellow toadflax is avoided by cattle due to secondary compounds such as linarin and choline, although they will occasionally eat it dried (Jacobs & Sing, 2006).

Although the invasiveness and persistence of yellow toadflax present challenges across various ecosystems, common mullein poses a different set of ecological concerns, particularly through its rapid growth and competitive dominance in disturbed habitats. Common mullein is a biennial with deep taproots that has evolved in its introduced range to be faster growing than populations in their native range and better defended from competing species, given that the genotypes introduced have increased growth and fecundity (Kumschick et al., 2013). Many plant species struggle to coexist with mullein because its large size limits light availability. Common mullein is typically found in disturbed areas and tends to get replaced by other species after early succession, although it can quickly reappear in a freshly disturbed area (Gucker, 2008). Hairs on the stems and leaves of common mullein prevent water loss from evaporation (Bare, 1979), and seeds germinate after 100+ years in soil (Kivilaan & Bandurski, 1981). This lengthy germination time is a difficult issue for invasive species managers to overcome, given that herbicide control would be required for an unrealistic number of years to achieve weed control.

To manage the negative effects that invasive weed species have on native species in restoration areas, restoration projects typically include a revegetation component in their restoration plan (Maron & Cockfield, 2008). Some commonly used restoration species in the riparian areas of northwestern U.S. include American sloughgrass (*Beckmannia syzigachne* Steud.), bluejoint reedgrass (*Calamagrostis canadensis* Michx.), and redtop (*Agrostis gigantea* Roth) (Hoag et al., 2011). The choice of species used depends on area conditions such as hydrologic regime, elevation range, acidity tolerance, and flood tolerance (Hoag et al., 2011). Another restoration species is annual ryegrass (*Lolium multiflorum* Lam.); this annual grass helps aid natural succession which assists in restoration of native species in areas where water runoff and potential soil erosion are not short-term concerns (Fields-Johnson et al., 2012). Compared to other treatments such as planting a conventional seed mix and a "tree compatible" seed mix, areas restored with annual ryegrass result in higher native tree survival as well as herbaceous native species richness in a restoration area (Fields-Johnson et al., 2012). Restoration species can also be affected by environmental factors such as soil pH and hydrological regimes, as well as land features that can limit soil availability and change nutrient/mineral concentrations (Hoag et al., 2011), which makes selecting the ideal species a difficult choice.

Study Goals and Objectives

My study seeks to better understand the ecological consequences of dredge tailings in post-mining restoration areas, particularly regarding vegetation patterns and invasive species presence. Focusing on the Red River Narrows restoration project in Idaho, my research aims to evaluate how dredge tailings and associated disturbances influence plant community recovery and the success of restoration efforts.

Dredge tailings are the by-products of raw materials mining. When rocks and minerals are crushed and washed, the waste carries to settling ponds where the material is collected (Society for Mining, Metallurgy & Exploration, 2021). Most tailings are removed in channel restoration, though some may be left behind. These dredge tailings are typically large expanses of bare tailing material which look like gravel, leaving an area where invasive species can and do thrive. The potential implications associated with dredge tailings are not limited to the establishment and retainment of invasive plant species. Minerals in tailings, such as mercury, are of concern regarding leaching into the surrounding ground and water (Ashley et al., 2002).

The presence of dredge tailings and the disturbance associated with removing them creates challenges for the establishment and retention of healthy, native plant populations in restoration areas. Challenges include an environment with inadequate conditions for native species to reestablish, which includes the presence of bare tailing materials, exposed substrate from tailing removal, and potential mineral leaching in the area, allowing invasive species to persist. In reference to this project, substrate is defined as a substance or surface that an organism grows and lives on and is supported by (Cambridge Dictionary, 2025). An area of concern regarding dredge tailings is the Red River Narrows restoration project completed by the U.S. Forest Service near Elk City, Idaho. Similar restoration projects complete work in stages, with channel work, material hauling, and replanting completed in distinct phases (Grinde, USFS, personal communication, 3/20/2024). However, the Red River Narrows project did not complete the leveling or removal of all of the tailings. Therefore, the overarching goal of my case study is to assess vegetation changes within the Red River Narrows restoration project area since 1984. My case study has three main objectives:

1. Estimate overlap between areas dominated by invasive species and those with dredge tailings and exposed substrate.
2. Demonstrate changes in vegetation pre- and post-restoration.
3. Discuss broader implications for restoration planning and completion, long-term monitoring, invasive species, herbicide treatments, and other factors based on the results.

I hypothesize that there will be proportionally more overlap between invasive areas and those areas classified as dredge tailings and exposed substrate, compared to other classified types (forest/shadows, water, herbaceous). I hypothesize that the areas with the greatest vegetation changes between pre- and post-restoration will be in areas with tailings removed.

CHAPTER TWO

MATERIALS AND METHODS

Project Setup

To determine whether areas with invasive species co-occur with mining dredge tailings and exposed substrate, I reached out to the Nez Perce-Clearwater National Forest fisheries biologist and hydrologist in spring 2024, who play a large part in forest river restoration projects. They directed me to some older projects and I chose to focus on the Red River Narrows restoration project which was completed about 12 years ago. The age of this project allows me to evaluate how plant communities changed with time after channel restoration. The Red River Narrows project occurred over multiple years and completed tree and grass/forb revegetation during the later stages of the project. The Red River Narrows project area is roughly 30 ha in size and is located between two private land parcels along Red River, 16.7 km south of Elk City, Idaho.

Once I decided which channel restorations to investigate, I contacted three relevant natural resource managers to fill in the gaps on this older project. According to the Nez Perce-Clearwater National Forest fisheries biologist, project data associated with older restorations have been limited since the forest supervisor's office was moved around two years ago, and their location is unknown. With restoration data provided by the Nez Perce-Clearwater National Forest, it is known that the Red River Narrows project was completed with the assistance and input of the Nez Perce Tribe. In the decision memorandum from 2005, it was determined that the tribe would complete vegetation monitoring of the restoration project. A decision memorandum is related to an agency's decision on a government project and typically documents the purpose

and need for action, plan conformance, compliance with NEPA, consultation, decision and rationale, and implementation date (DOI, 2018). The main project manager in the Nez Perce Tribe for Red River Narrows stated that vegetation monitoring using circle plots occurred over the first five years post-restoration and that survival rates of plants in the revegetation effort were monitored. Grass seeding was completed for revegetation, and because records were limited, it *likely* contained a native seed mix which included a sterile annual rye, though there is still annual rye in the area today.

The decision memo for Red River Narrows dictates that the restoration project will focus on road improvements and road decommissions, soil restoration of landings, and culvert removal/replacements. This document also explicitly stated, "Areas of bank disturbance will be seeded and mulched immediately upon completion of work in that area." It is unclear if mulching was completed as directed. Under the monitoring and effectiveness section, the priorities were three-fold: 1) weeds will be monitored and treated, 2) revegetation will be monitored for effectiveness, and 3) those areas that do not revegetate will be reseeded. Due to a lack of restoration information available from the Nez Perce National Forest and the Nez Perce Tribe, it is assumed that the grass seeding completed for revegetation included a native seed mix with annual ryegrass which now dominates the current grassy areas in the restoration project area.

Most of the data related to the Red River Narrows restoration project are from the project planning stages. There are many improvement plan diagrams (Figure 1). The most relevant part of Figure 1 are the yellow sections which depict the areas that the USFS and the Nez Perce Tribe had tailings removed and revegetation completed in the Red River Narrows restoration project.

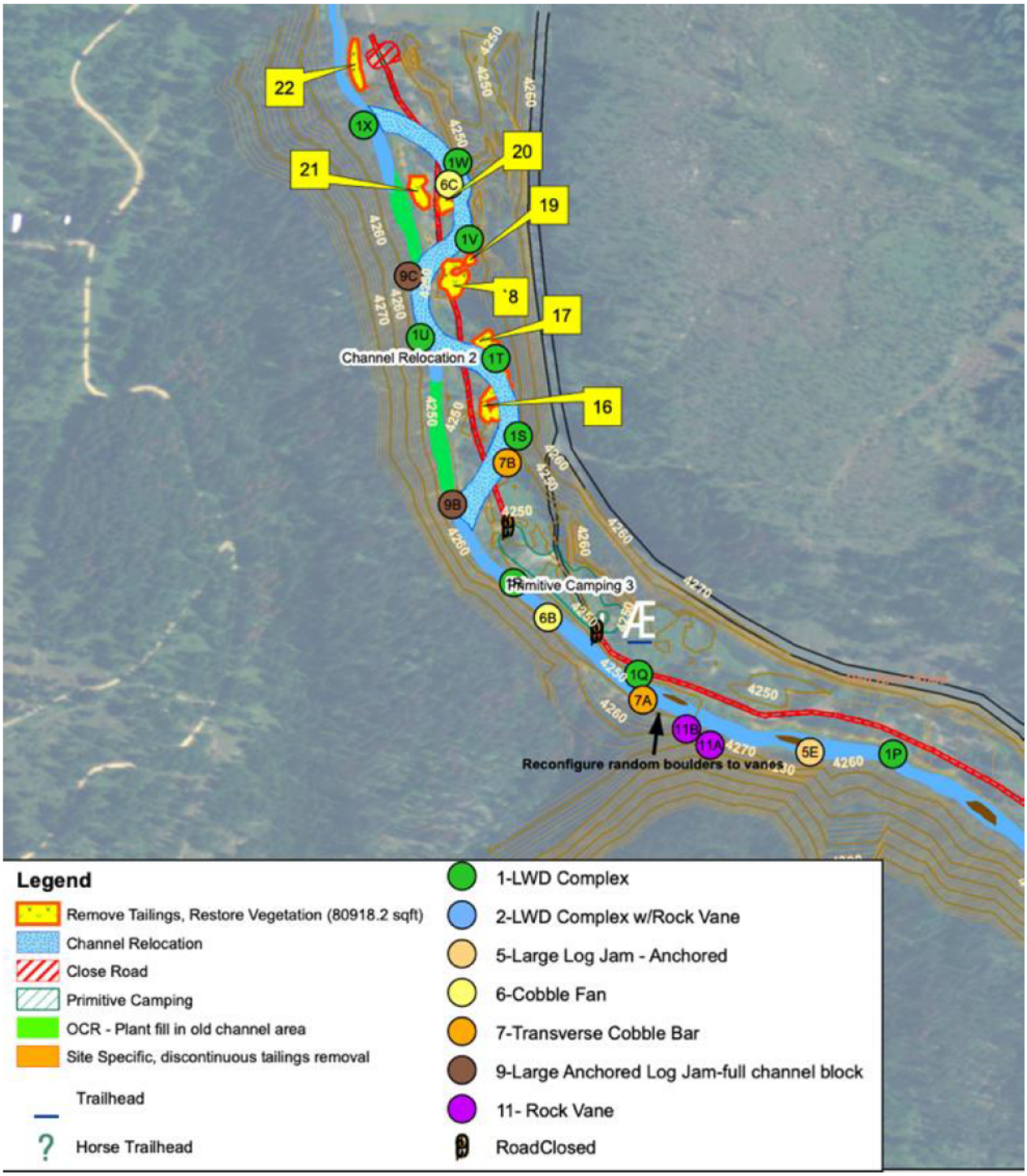


Figure 1. Section of Red River Narrows stream improvement plan depicting specific channel restoration techniques (i.e., log jam, cobble fan) and areas for tailing removal, revegetation, and road decommissioning. From the Red River Narrows Stream Improvement plan (USFS, 2008).

Data Collection

The Red River Narrows restoration project area is a small project area at roughly 30 ha, so I conducted a full census of invasive plant species on August 17, 2024. I chose not to census native species because my case study is focused on changes in invasive species. Within each sampling of individual invasive plant species, I keyed each plant to species, which included Idaho noxious weed species (Invasive Species of Idaho, 2025). I walked the 30-ha project area along the eastern and western side of the Red River and inventoried for all weed species, in which I found spotted knapweed, yellow toadflax, and common mullein. The United States Forest Service (USFS) guidance for capturing the spatial extent of a weed population is to document the apparent perimeter of the area that contains that weed species with that polygon perimeter becoming the inventory (Figure 2) (Natural Resource Manager, 2023).

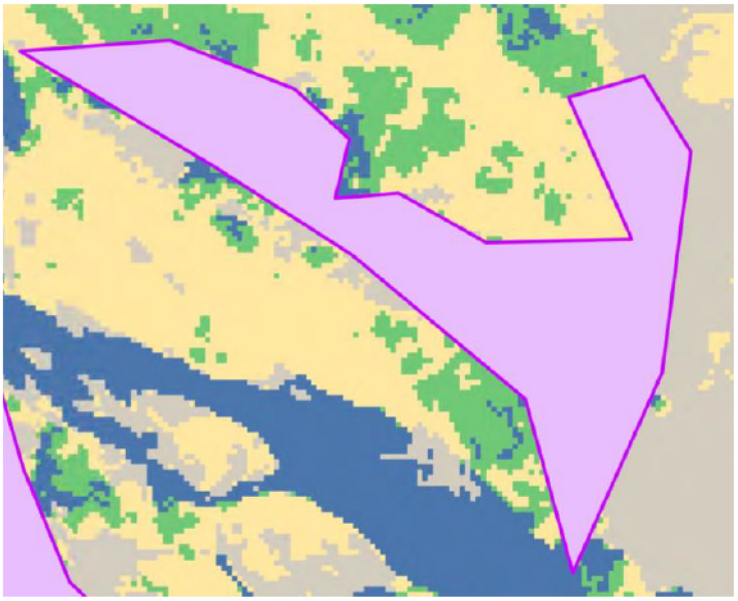


Figure 2. Lavendar polygon represents example of an invasive inventory/population on Red River Narrows restoration project. Tuthill: From personal data collection.

Using this guidance from USFS, I surveyed the restoration project area by walking the apparent, approximate perimeter (within 1.5 m) of the weed populations within the restoration project boundary relative to where the population stopped, and then drew a polygon with

associated information, which included date and species, using the application Field Maps (ESRI, 2025). All invasive plant species were included in this survey, and every plant was accounted for through this survey. If there was an area with one or more individual plants which were invasive plant species (i.e., spotted knapweed), I would capture that spatially with a polygon in Field Maps. If there was a distinct separation of at least 1.5 m between plants, each separate polygon was considered an introduced population and designated by a separate polygon.

After collecting my data in Field Maps, I synced and loaded the data into the ArcMap Natural Resource Manager via TESP/IS protocols (Natural Resource Manager, 2023). I created a vector map layer that depicted my field measurements at the Red River Narrows channel restoration project area. The apparent perimeter of each weed population was visually assessed and was distinct (Figure 3). I documented one population (represented as a polygon) of yellow toadflax, one population of common mullein, and 11 populations of spotted knapweed.



Figure 3. Example of the apparent perimeter (center orange line) of spotted knapweed (*Centaurea maculosa*) inventory (left) at Red River Narrows restoration project. Species on the right is annual ryegrass. Photo taken on August 17, 2024, by Jane Tuthill.

Unsupervised Classification

An unsupervised classification is an algorithm that separates classes within an image based on statistical differences in the spectral characteristics of pixels. I downloaded two National Agriculture Imagery Program (NAIP) raster files from Earth Explorer with 2024 imagery that included the restoration area. I merged these rasters together and used the Classification wizard in ArcPro to complete a pixel-based, ISO Cluster unsupervised classification. ISO Cluster is the unsupervised classification classifier in ArcPro that uses the migrating means technique. The following settings were used:

- **Configure:** Classification Method: Unsupervised, Classification Type: Pixel based, Classification Schema (4 mentioned above), Output Layer Type: Raster Layer
- **Train:** Classifier: ISO Cluster, Maximum number of classes: 10, Maximum number of iterations: 20, Maximum number of cluster merges per iteration: 5, Maximum merge distance: 0.5, Minimum samples per cluster: 20, Skip Factor: 10
- **Assign classes:** I was then able to use this tool to assign each of the 10 unsupervised classifications to the 4 chosen classes (water, exposed substrate/tailings, forest/shadows, herbaceous). I used NAIP imagery as a reference to visually choose which classes belonged to each group.
- **Reclassifier:** I made a few reclassifications, mainly near the edge of the road where trees/shadows were classified as water. No other edits were made.

The setting I customized during the unsupervised classification was the maximum number of classes, which was most accurate to NAIP imagery at 10 classes. Initially I attempted

an unsupervised classification using the default (5) as the maximum number of classes which did not effectively differentiate between the chosen classes in the true extent of the area, so I tried again with 10 and then assigned each of these classes to the 4 chosen classes (water, exposed substrate/tailings, forest/shadows, herbaceous). I also attempted unsupervised classification with 15 and 20 classes to compare accuracies with reference data (Figure 4). None of these classifications accurately separated tailings from exposed substrate so they were combined into the same class.

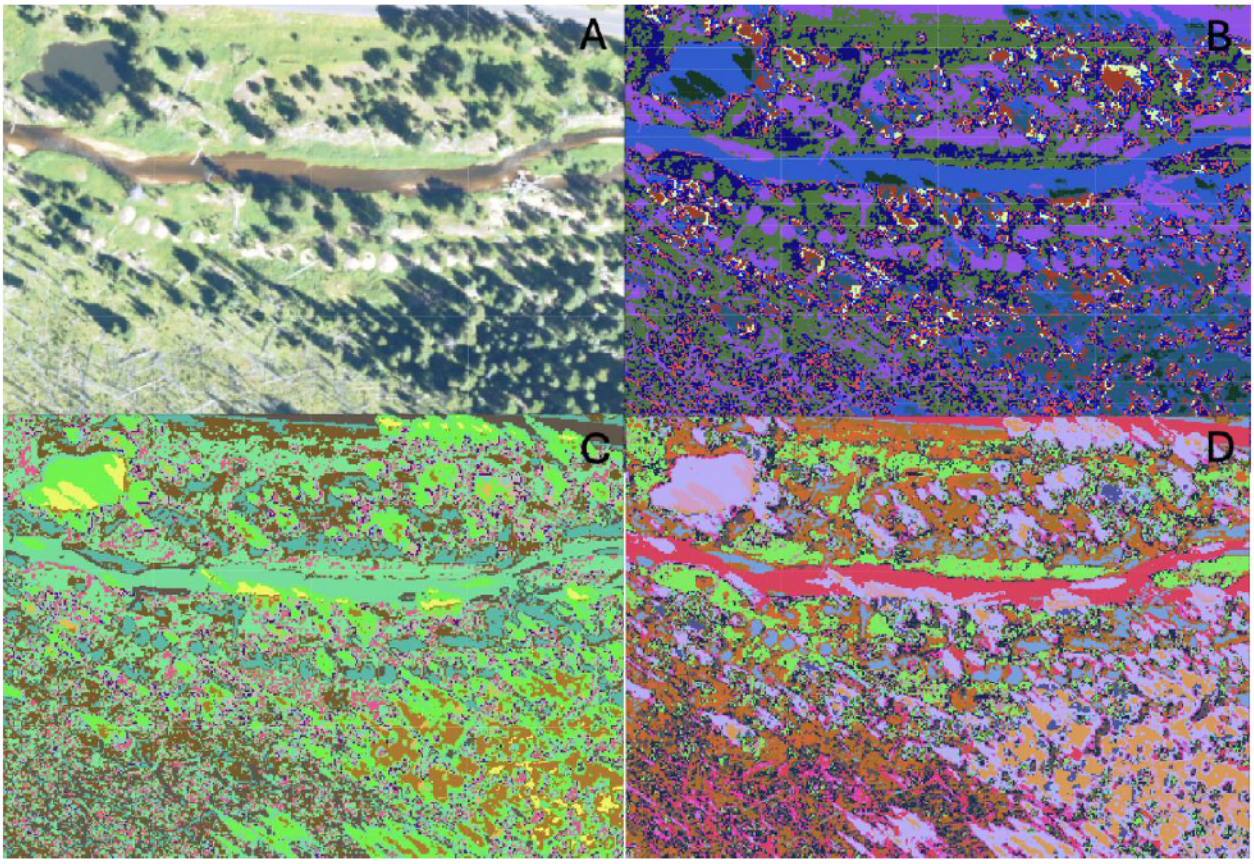


Figure 4. Unsupervised classification of B) 10 classes, C) 15 classes, and D) 20 classes, compared to true extent of A) NAIP imagery.

To estimate the accuracy of my classification, I conducted an accuracy assessment on my classification using the ArcPro Accuracy Assessment tool. I used the Create Accuracy Assessment Points tool in ArcPro to create 60 points (15 per class) and visually verified each

point using original high resolution NAIP imagery. My sampling strategy was stratified random. Foody (2002) states that "it seems unlikely that a single universally acceptable standard for accuracy assessment and reporting can be specified", and this number of accuracy assessment points was chosen due to the small project area of about 30 ha. I was not able to compare to another classified raster because there was not an available comparable NAIP classification. Once the manual verification of each accuracy assessment point was completed, the data were transferred into an Excel spreadsheet in which overall accuracy (Equation A), comission error (Equation B), ommission error (Equation C), user's accuracy (Equation D), producer's accuracy (Equation E), and the kappa coefficient (Equation F) were calculated.

A) $Overall\ Accuracy = \frac{\#\ Correctly\ Classified\ Sites}{Total\ \#\ Sites}$

B) $Comission\ Error\ by\ class = \frac{\#\ False\ Positive\ Class\ Sites}{\#\ False\ Positive\ Class\ Sites + \#\ True\ Positive\ Class\ Sites}$

C) $Omission\ Error\ by\ Class = \frac{\#\ False\ Negative\ Class\ Sites}{\#\ False\ Negative\ Class\ Sites + \#\ True\ Positive\ Class\ Sites}$

D) $User's\ Accuracy = 100\% - Comission\ Error$

E) $Producer's\ Accurary = 100\% - Omission\ Error$

F) $Kappa\ Coefficient\ (k) = \frac{p_o - p_e}{1 - p_e}, where\ p_o = observed\ agreement\ and\ p_e = expected\ agreement$

Pixel Counts

To determine pixel counts in each class for the invasive areas to describe the invasive region, I used the Zonal Histogram tool in ArcPro. The input raster included the classified raster data, and the zones were the invasive inventory polygons vector dataset (including all 13 weed inventory polygons), resulting in each polygon and how many pixels are included from each class. To determine pixel counts in each class for the noninvasive areas to describe the

noninvasive region, I used the Difference Vector tool to create a new vector dataset, resulting in the project area polygon minus the inventory polygons and then repeated the Zonal Histogram calculation. I exported these data to Excel and used it to create bar graphs of the pixel results.

Statistics and Pixel Calculations

Because I essentially completed a census by inventorying the entire project area for weeds and completed an unsupervised classification on the entire project area, I used descriptive statistics to represent my results. Pixel results are reported in both % of pixels and area of pixels. Area of pixels was calculated by multiplying the NAIP resolution cell size X by cell size Y (Equation G). The resolution of NAIP imagery post-2018 is 0.6 m (Utah Geospatial Resource Center, 2024), which makes the area of one pixel 0.36 m^2. To determine the pixel area for one class (i.e., water), I multiplied the pixel area by the number of pixels in that class (Equation H).

G) $Pixel\ Area\ (m^2) = Cell\ Size\ X\ (m) \times\ Cell\ Size\ Y\ (m)$

H) $Pixel\ Area\ of\ a\ Class\ (m^2) = 0.36\ m^2\ \times\ \#\ of\ Class\ Pixels$

Change Detection Analysis

A change detection analysis detects and analyzes changes in the same geographical area over time. Due to the lower resolution NAIP data pre-restoration (2008), I could not use NAIP data to complete a change detection analysis. Given this limitation and the accreditation of LandTrendr's use by the National Parks Service, U.S. Fish and Wildlife Services, and studies such as Yang et al (2018), I used various UI LandTrendr GEE Apps to illustrate vegetation changes pre- and post-restoration. These UI LandTrendr Apps are found on Google Earth Engine and do not allow for customizations, but rather provide a simple change detection analysis of an area. LandTrendr uses all LandSat data (LandSat 6-9) and masks atmospheric effects such as clouds, shadows, and snow. I used Normalized Difference Vegetation Index (NDVI) as the index,

given that it quantifies vegetation greenness, health, and density which is crucial for long-term river channel restoration success (Buchanan et al., 2014, Buchanan et al., 2012, Rosgen, 1994). I used the UI LandTrendr Change Mapper to demonstrate how vegetation significantly changed with time pre- and post-restoration between 1984 and 2023. I used the UI LandTrendr Fitted Index Delta RGB Mapper to visualize significant vegetation change over time while providing a sense for spectral intensity between 1985 and 2023.

AI Disclosure

At no point during this project did I use any AI tools.

CHAPTER THREE

RESULTS

Weed Inventories

When collecting weed inventory data at Red River Narrows restoration project, I created 13 geospatial polygons which depict the areas the weed species occupy. I documented one population of yellow toadflax (*L. vulgaris*), one population of common mullein (*V. thapsus*), and 11 populations of spotted knapweed (*C. maculosa*) (Figure 5).

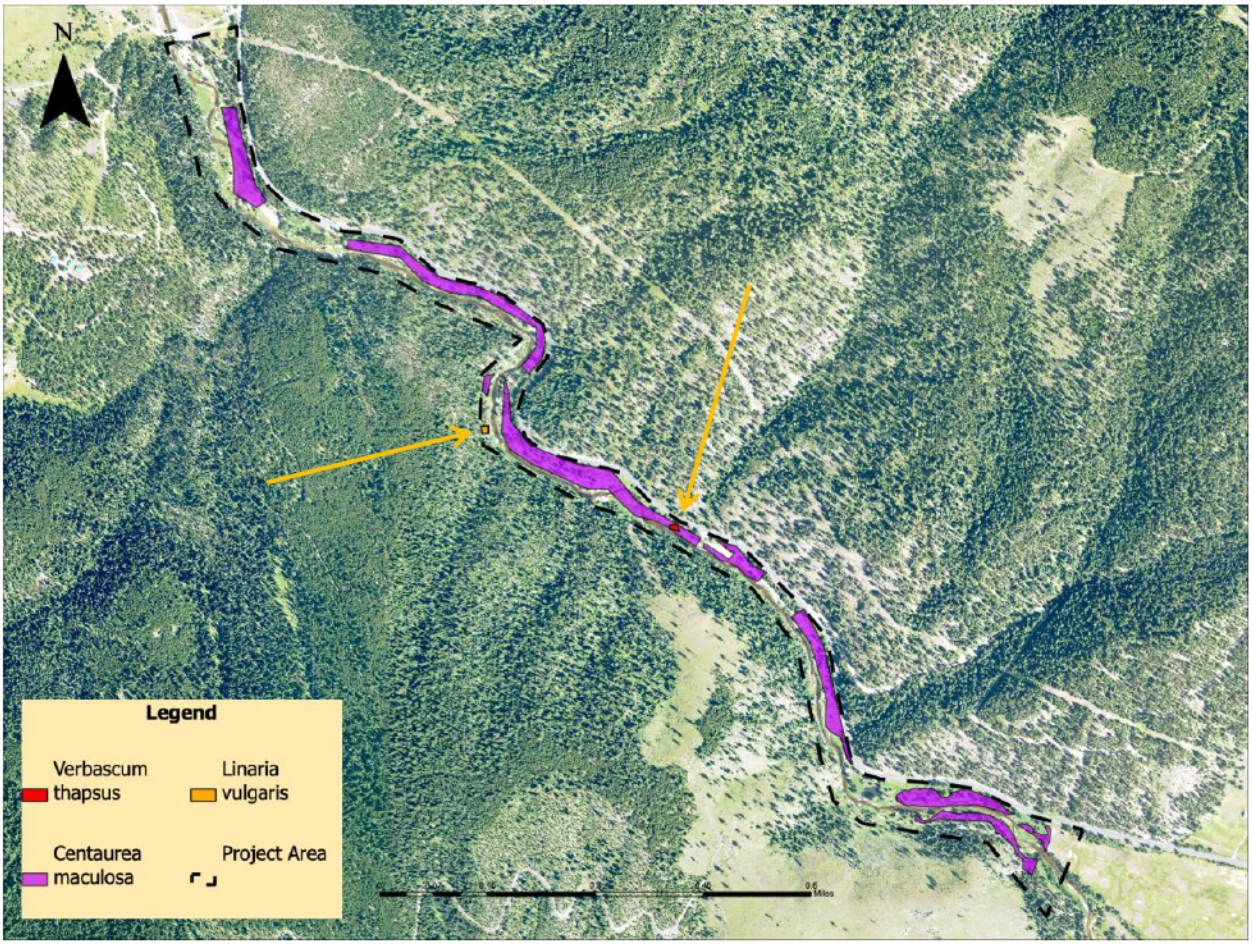


Figure 5. Map of Red River Narrows channel restoration area with associated weed inventories. Areas without weed inventories within the project area is considered the noninvasive area. Yellow arrows indicate small weed inventories.

Unsupervised Classification

The results of the unsupervised classification and pixel counts indicate that the invasive region of the Red River Narrows restoration project has 1,923 pixels, or 692.3 m^2, while the noninvasive region has 4,400 pixels, or 1,584 m^2. These values indicate that the invasive region makes up 30.4% and that the noninvasive region makes up 69.6% of the Red River Narrows restoration area. A potentially confounding result is the area and percentage of the invasive region that is classified as water (Table 1, 2). This result is problematic because none of the invasive species inventoried were aquatic species, making it unlikely that measured invasive species could survive there. The cause of this inaccuracy could be an issue with the location accuracy of the device I used to collect the data or a misclassification error.

Table 1. Invasive and noninvasive region areas (m^2) of the Red River Narrows restoration project made up by each class (water, exposed substrate/tailings, forest/shadows, herbaceous).

Class	Invasive Area (m^2)	Noninvasive Area (m^2)
Water	101.9	353.5
Exposed Substrate/Tailings	238.3	297
Forest/Shadows	145.8	392
Herbaceous	206.3	541.4

Table 2. Invasive and noninvasive region pixels (%) of the Red River restoration project made up by each class (water, exposed substrate/tailings, forest/shadows, herbaceous).

Class	% of Invasive Region	% of Noninvasive Region
Water	14.7	22.3
Exposed Substrate/Tailings	34.4	18.8
Forest/Shadows	21.1	24.8
Herbaceous	29.8	34.2

Exposed substrate and tailings in the invasive region were nearly double the pixel percentage of the noninvasive region (34.4% vs. 18.8%, respectively) (Figure 6). It is more difficult to compare the pixel areas by class (Figure 7) due to the noninvasive region making up nearly 70% of the restoration project but regardless, the pixel area of exposed substrate/tailings is nearly the same in invasive and noninvasive regions (238 vs. 297 m^2).

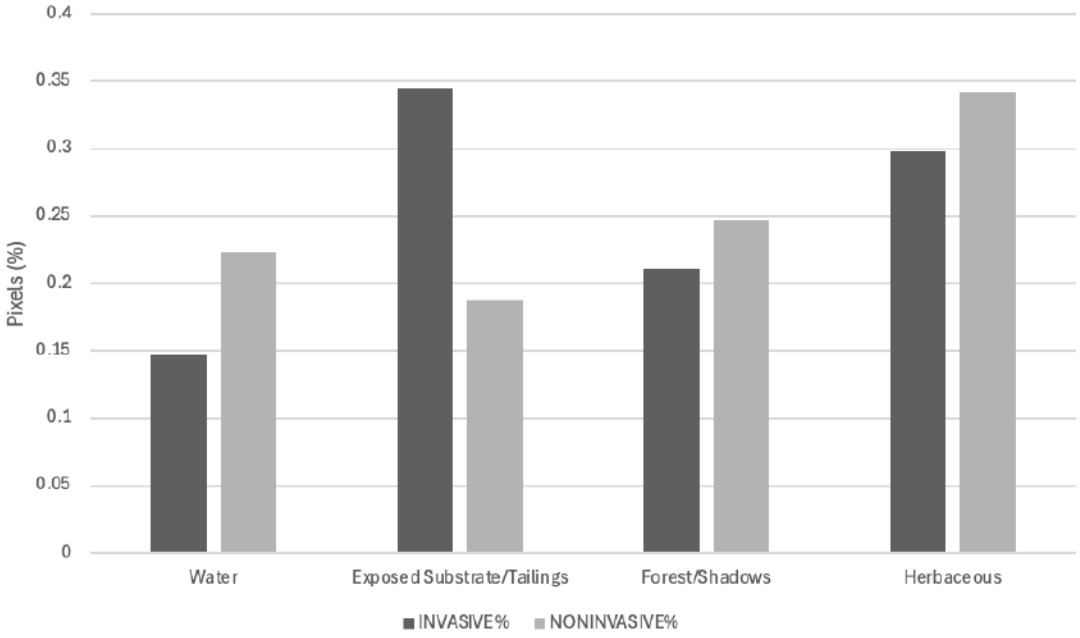


Figure 6. Comparison of percentage of pixels that make up the invasive (dark grey) and noninvasive (light grey) regions of the Red River Narrows restoration project in each class (water, exposed substrate/tailings, forest/shadows, herbaceous).

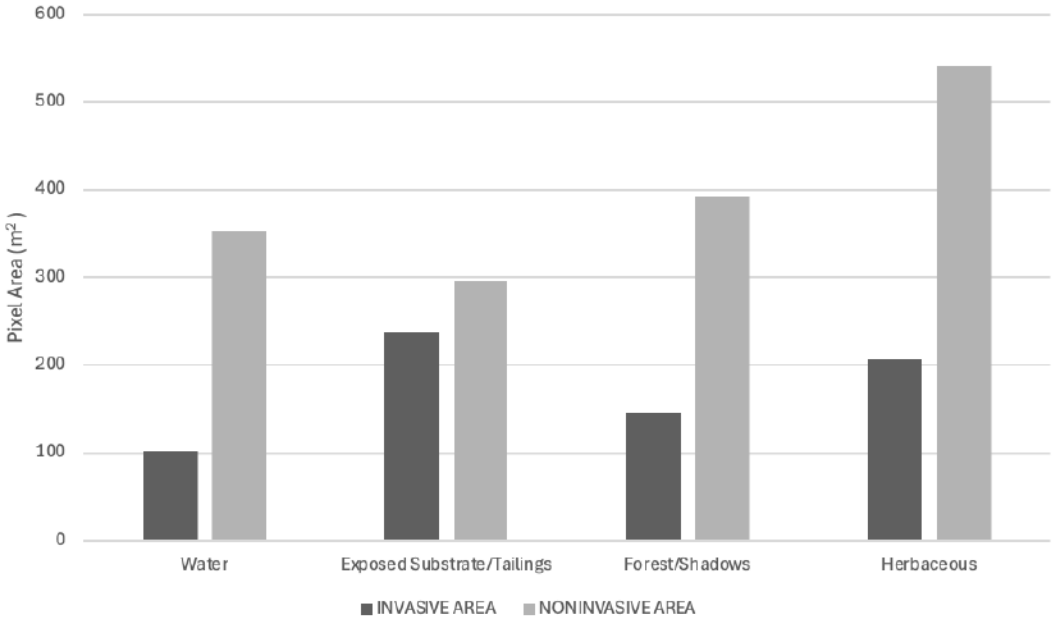


Figure 7. Comparison of pixel areas that make up the invasive (dark grey) and noninvasive (light grey) regions of the Red River Narrows restoration project in each class (water, exposed substrate/tailings, forest/shadows, herbaceous).

Accuracy Assessment of Unsupervised Classification

The classification performed well compared to reference data with some classes (i.e., forest/shadow class), while it largely failed in others (i.e., water class) (Table 3). The error matrix representing reference data compared to classified data depicts correctly and incorrectly classified data (Table 3). The overall accuracy of the unsupervised classification was 68.3% and the Kappa Coefficient was 49.5%. This overall accuracy value can be interpreted as saying roughly 3 times out of 10, the class will not correspond to reference data. Another way of explaining this is that ~70% of the time, the classification will match up to "real-life" reference data. The Kappa Coefficient value indicates that the classified and reference data are in moderate agreement with each other (McHugh, 2012).

Table 3. Contingency table or error matrix representing reference data (NAIP) compared to classified data. Rows are mapped classes generated from remote sensing data. Underlined values in the table represent areas that were correctly classified.

		Reference Data				
	Classes	Water	Exposed Substrate/Tailings	Forest/Shadow	Herbaceous	Total
Classified Data	Water	1	0	0	0	1
	Exposed Substrate/Tailings	1	9	0	1	11
	Forest/Shadow	7	0	26	7	40
	Herbaceous	0	1	2	5	8
	Total	9	10	28	13	60

The water class has a high omission error (89%), which describes what pixels belonging to one class area were included in another class, also known as false negatives (Table 4). The producer's accuracy complements the omission error, describing the map accuracy from the point of view of the map maker, and demonstrates high accuracy in the exposed substrate/tailings class (90%) and forest/shadow class (93%). The commission errors were overall much lower than omission errors, showing false positives. The user's accuracy complements the commission error, describing the map accuracy from the point of view of a map user, and demonstrates high accuracy for the exposed substrate/tailings class (82%).

Table 4. Summary of omission errors, commission errors, producer's accuracies, and user's accuracies for the four classes (water, exposed substrate/tailings, forest/shadow, and herbaceous).

	Water	**Exposed Substrate/Tailings**	**Forest/Shadow**	**Herbaceous**
Omission Error	0.89	0.10	0.07	0.44
Commission Error	0.00	0.18	0.35	0.38
Producer's Accuracy	0.11	0.90	0.93	0.56
User's Accuracy	1.0	0.82	0.65	0.63

Change Detection Analysis

The UI LandTrendr Change Mapper's changes in NDVI magnitude with vegetation loss demonstrate where tailing removal had the greatest effect on vegetation (Figure 8). Using the inspector feature, you can click on a pixel to see the magnitude and pre-magnitude values, along

with the year and a graph with NDVI changes over time. An example of this is in the upper right corner of Figure 8, where the pixel chosen was one of the brightest colored pixels in the northwest corner of the restoration area where tailing removal was completed. There is a steady NDVI until around 2008 when it sharply drops and gradually rises between 2010 and 2023 (Figure 8). This trend corresponds with the restoration project, as the restoration began during this time. The area with the most change in NDVI magnitude as depicted by the brighter green color also had the most channel restoration work completed (yellow sections, Figure 1) and therefore the greatest loss and subsequent change in vegetation. The areas with the lowest NDVI magnitude values (darker blue pixels) have a steadier trend of NDVI, with a drop around 2010.

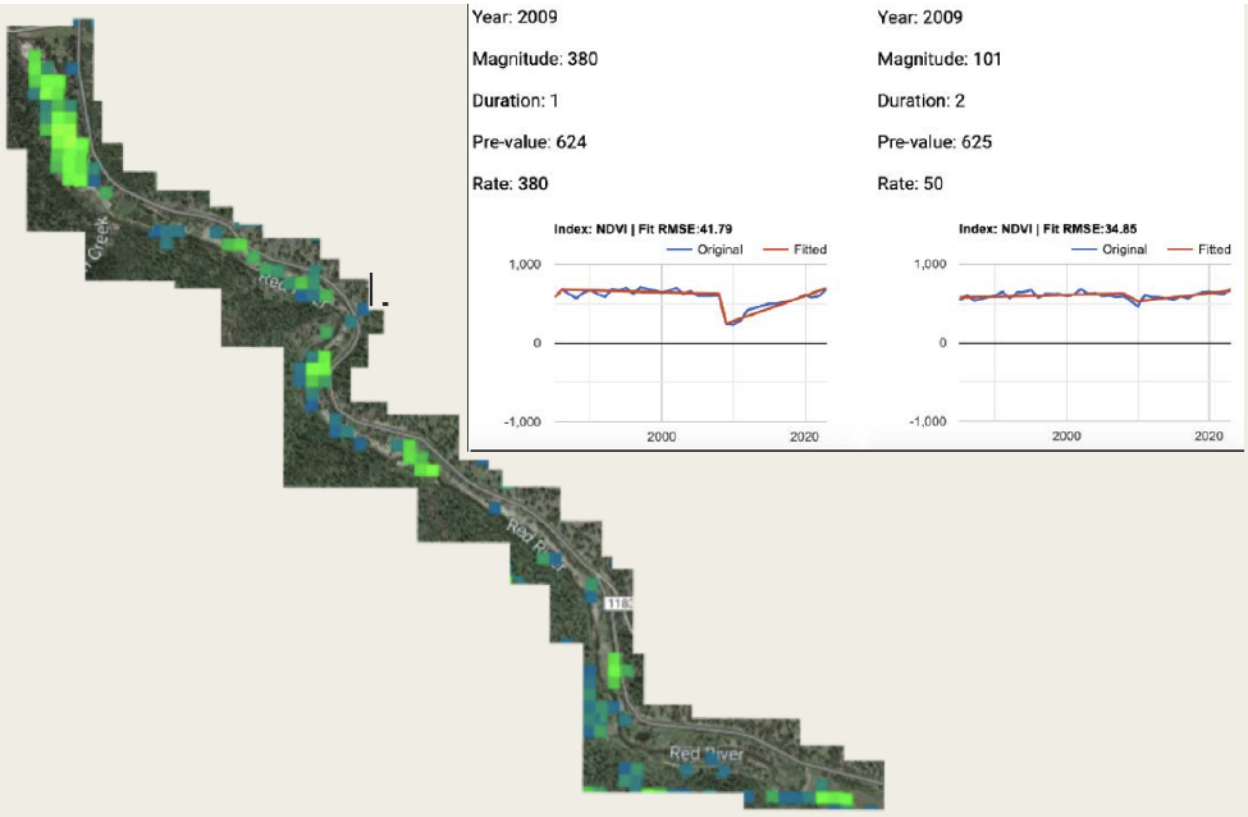


Figure 8. Changes in NDVI magnitude with vegetation loss between 1984 and 2023 in the Red River Narrows restoration project, with lighter colors depicting greater NDVI magnitude changes and darker colors with lesser NDVI magnitude changes. Upper right window depicts examples of results of singular pixel NDVI magnitude changes between 1984 and 2023. Left: Bright green pixel magnitude data. Right: Darker blue pixel magnitude data.

The RGB color map from the UI LandTrendr Fitted Index Delta RGB Mapper representing spectral band or index values (in this case, NDVI) at three time slices (red=1985, green=2005, blue=2023) largely demonstrates more NDVI changes between 1985 and 2005 (Figure 9). Red, green, and blue are mixed by weighting of the spectral intensity for the year represented by each color. This mixing visualizes change (or non-change) over time and provides a sense for spectral intensity. The more yellow sections are NDVI changes between 1985 and 2005 while the more pink sections are changes between 1985 and 2023. There appears to be slightly more light pink pixels than yellow in the project area, and the color white which would depict no change is absent from the map. If we were expecting NDVI to change the most during and after restoration, that would mean we would see light blue and light green pixels, of which there are a few closest to the river on the most northern and southern sections of the restoration.

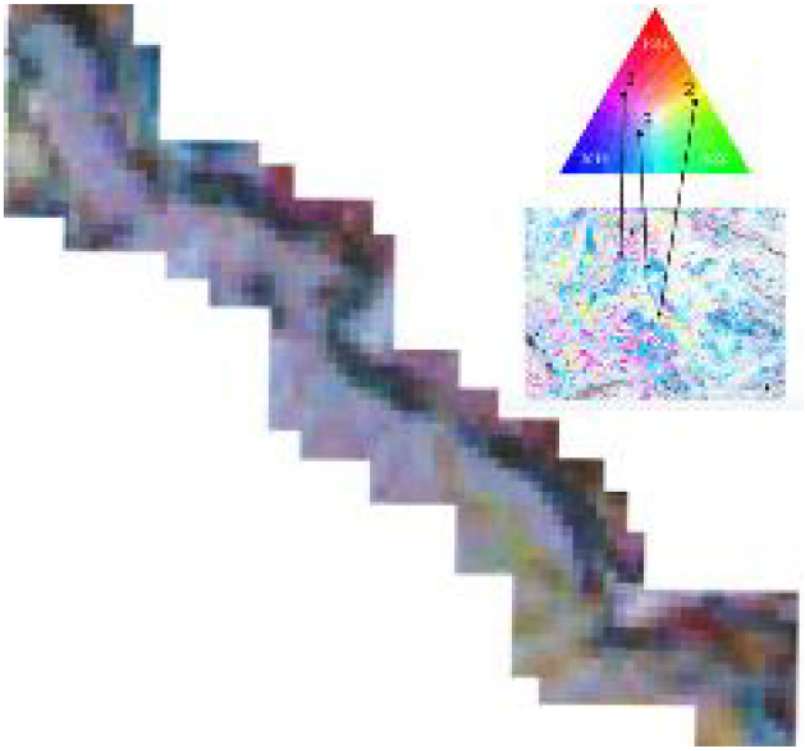


Figure 9. Changes in NDVI between 1985 and 2023 in the Red River Narrows restoration project from the UI LandTrendr Fitted Index Delta RGB Mapper. Red represents 1985, green represents 2005, and blue represents 2023. Upper right corner: diagram from LandTrendr as example of how to interpret the RGB Mapper results.

CHAPTER FOUR

DISCUSSION

Considering that there are nearly double the percentage of exposed substrate/tailings in the invasive region versus noninvasive region (34% vs. 19%) and that there are more weed species located on exposed substrate/tailings pixels, there seems to be an overlap between areas dominated by weed species and those with dredge tailings and dredge tailing removal. This finding is important in the context of river restoration projects, as dredge tailings are commonly encountered and using the appropriate methods to remove tailings and successfully complete long-term revegetation in these areas is crucial to river restoration success (Buchanan et al., 2014; Buchanan et al., 2012; Rosgen, 1994). Those responsible for river restoration planning and those involved in the river restoration work should be aware of this potential long-term overlap between weed species and dredge tailings.

Implications of Unsupervised Classification

The decision of whether to remove tailings, level tailings, or leave them during river restoration projects is largely variable, likely because there is limited literature or guidance on the subject. Although these dredge tailings are largely unstudied in the context of restorations and weed species, there is literature associated with the impacts of tailings. Minerals in tailings, such as mercury, are of concern regarding leaching into the surrounding ground and water (Ashley et al., 2002). It is unknown what, if any, minerals are leaching out of the tailings at the Red River Narrows restoration project, and that assessment should be added in to the restoration project planning and monitoring process.

In addition to the biological challenges posed by invasive species on dredge tailings, the physical and chemical properties of the soils in these areas further complicate restoration efforts. The Red River Narrows restoration area has a mix of Cryaquepts-Cyumbrepts complex and Entisols soil (Soil Survey Staff, 2025). The Cryaquepts-Cryumbrepts complex is characterized by a mix of poor to good drainage with occasional flooding, while the Entisols have good drainage and frequent flooding (Soil Survey Staff, 2025). Soils frequently associated with the presence of tailings are characterized by poor drainage and the presence of gravel throughout all horizons (Crops for Southland, 2002). Tailings have a variable topsoil depth of 10-30 cm with weakly developed or absent subsoil structure (Crops for Southland, 2002). With this small amount of topsoil the risk of erosion is increased, especially for areas with no vegetation cover. Average soil pH in unmined areas is higher than soil in mined areas with tailings (Xu et al., 2023). This increased pH is caused by the nitrification of excess nitrogen content of the ammonium ion (NH_4+-N) which produces hydrogen ions (H^+) and migrates through water, unless it is removed from the tailings (Xu et al., 2023). However, eight years after woody crops such as *Salix* (L.), *Populus* (L.), and *Alnus* (Miller) species were planted in dredge sediments, biological activity and QBS index (microarthropod groups) increased, though the potential risk of trace element (i.e., zinc) transfer to the environment is still a concern (Hartley et al., 2011). Overall, these features of dredge tailing soils are not promising for native plant species and revegetation efforts in river restoration projects.

To mitigate the presence of soil contaminants, such as heavy metals from mining dredge tailings, the use of certain plant species are used in restoration projects, also known as phytoremediation (Dong et al., 2023). The ryegrass genus (*Lolium*) produce phytoremediation effects in decomposing cadmium and lead from soil with the assistance of chelating agents such

as citric acid and oxalic acid (Dong et al., 2023), as well as in decomposing cadmium and zinc pollution (Gadepalle et al., 2008). The addition of phosphorous fertilizers to heavy metal contaminated soils is also effective in phytoremediation with ryegrass (Waterlot & Hechelski, 2019). The phytoremediation abilities of ryegrass in the context of heavy metals indicates this genus is an appropriate restoration choice for mining dredge tailings, though the biomass should be removed to truly remove heavy metals from the area.

The limitations of my use of unsupervised classification include errors with unsupervised classification software, lack of ground-truthing, atmospheric contamination, and sensor errors. This classification's overall accuracy assessment value was 68.3%. The best classifications have higher overall accuracy values than this, such as the National Land Cover Database (NLCD) which ranges between 77-90% (Wickham et al., 2023), and a common aim of target accuracy is ~85% (Wulder et al., 2006). Another limitation is the seasonality during which the NAIP imagery was taken, because there is vegetation on some of the tailings. If there had been available fall remote sensing data to minimize the presence of this vegetation, the classification could have been more accurate regarding the tailings. However, the presence of vegetation on these tailings is important because it is not all invasive species, some is made up of annual ryegrass (Figure 10).



Figure 10. Dredge tailings left at Red River Narrows restoration project. Photo taken on August 17, 2024, by Jane Tuthill.

The presence of dredge tailings and the disturbance associated with their removal creates challenges for the establishment and retention of healthy, native plant populations in restoration areas. Challenges include an environment with inadequate conditions for native species to reestablish, which includes the presence of dredge tailing materials, exposed substrate from tailing removal, and the potential mineral leaching in the area, allowing invasive species to establish rather than native species. Invasive plants have self-protective mechanisms when exposed to heavy metals, and these areas may favor plant invasions due to higher tolerance of invasive plants to these heavy metals (Li et al., 2021). These conditions could explain the greater proportional overlap between exposed substrate/tailings in the invasive region compared to the noninvasive region.

Implications of Change Detection Analysis

Through my analysis, the demonstration of steady NDVI until about 2008 where it sharply drops and gradually rises between 2010 and 2023 is useful knowledge in the context of understanding how NDVI recovers after a high disturbance restoration activity, such as dredge tailing removal and river work. It is interesting to note that NDVI has just begun to recover to pre-restoration values since the drop in 2010, 13 years later, especially in the areas with the most NDVI change. The slow recovery of NDVI in those areas most impacted by restoration activities could be due to mineral leaching and soil acidification from tailings or from changes in surface and groundwater availability (Aguilar et al., 2012, Fu & Burgher, 2015), limiting the success of native species and restoration species revegetation. It would be interesting to use the same change detection analysis methods between multiple river restorations that include dredge tailings to determine whether this trend is widespread.

There are limitations to the LandTrendr methods being used for routine change detection analysis in restoration projects, mainly due to the lack of literature on the subject. Other limitations of this change detection analysis include lack of ground-truthing, atmospheric contamination, and LandSat sensor errors. However, the fact that LandTrendr GEE apps use more than one dataset improves the reliability of their use. The use of LandTrendr to determine significant changes in restoration areas is feasible, though it would be more ideal if various remote sensing data resolutions were available based on the restoration project's size and scale. Regardless, using LandTrendr is an easy and free way to assess long-term changes in various bands and indices. This process of monitoring river channel restorations could be expanded and improved upon by additionally examining downstream changes.

Building on the feasibility of LandTrendr for long-term monitoring, a NDVI analysis offers further insight into vegetation recovery and is increasingly used to evaluate restoration success. Various studies have analyzed NDVI to determine vegetation recovery of a restoration project (Wilson & Norman, 2018, Yang et al., 2018, Leon et al., 2012). Post-restoration values in a restored wetland had higher greenness and greater increases in greenness over time when compared to nearby control sites without restoration, indicating a successful restoration (Wilson & Norman, 2018). Yang et al. (2018) used LandTrendr to determine whether mines had been adhering to mining legislation related to revegetation. Using NDVI change detection analysis is an effective, frequently used tool that should be standard practice in ecological restorations.

Implications for Future River Restorations

Implications for Restoration Planning, Completion, and Monitoring

The presence and health of riparian vegetation is not just crucial in the context of channel stability, considering the shade and organic debris provided by the vegetation is also essential for fish and benthic organism habitat (Buchanan et al., 2012). To facilitate the establishment of riparian vegetation, bio- and geo-technical engineering techniques are suggested to stabilize newly formed streambanks (Buchanan et al., 2012). Some of these methods include branch packing, brush layering, brush mattresses, brush revetments, brush trenches, and crib walls (NRCS, 2007). These methods are used to establish woody vegetation to protect the new bank from erosion and may use roots to keep the structure together.

To control streambank erosion in a restoration that emphasizes reconstruction of a stream channel, like Red River Narrows, it is recommended to use the soil bioengineering methods of vertical bundles, live stakes, and stream barbs (NRCS, 2007). Vertical bundles (Figure 11) are

bundles of willow cuttings placed in vertical trenches along an eroding bank (NRCS, 2007), which gives them an advantage in stream systems with quickly fluctuating water levels due to at least part of the plant consistently having access to water.

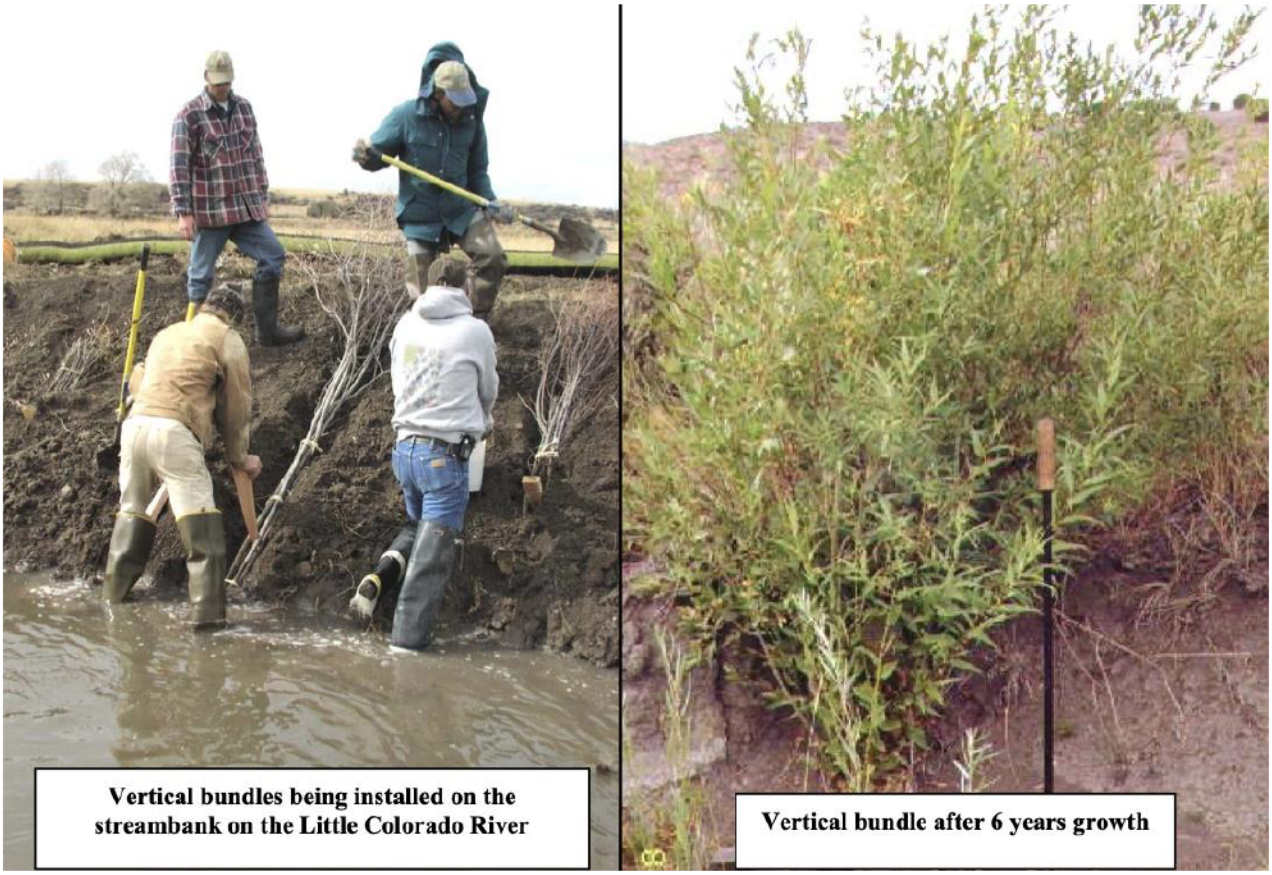


Figure 11. Vertical bundle installation and resulting vegetation after 6 years. From Hoag (2009).

Live stakes (Figure 12) are dormant stems, branches or trunks of live woody plant material inserted into the ground for bank erosion control and creation of riparian vegetation (NRCS, 2007). Live stakes are capable of forming a dense vegetative matrix as soon as two growing seasons after construction, though long-term plant survival depends on the specific site and requires long-term monitoring (Barrett et al., 2006).

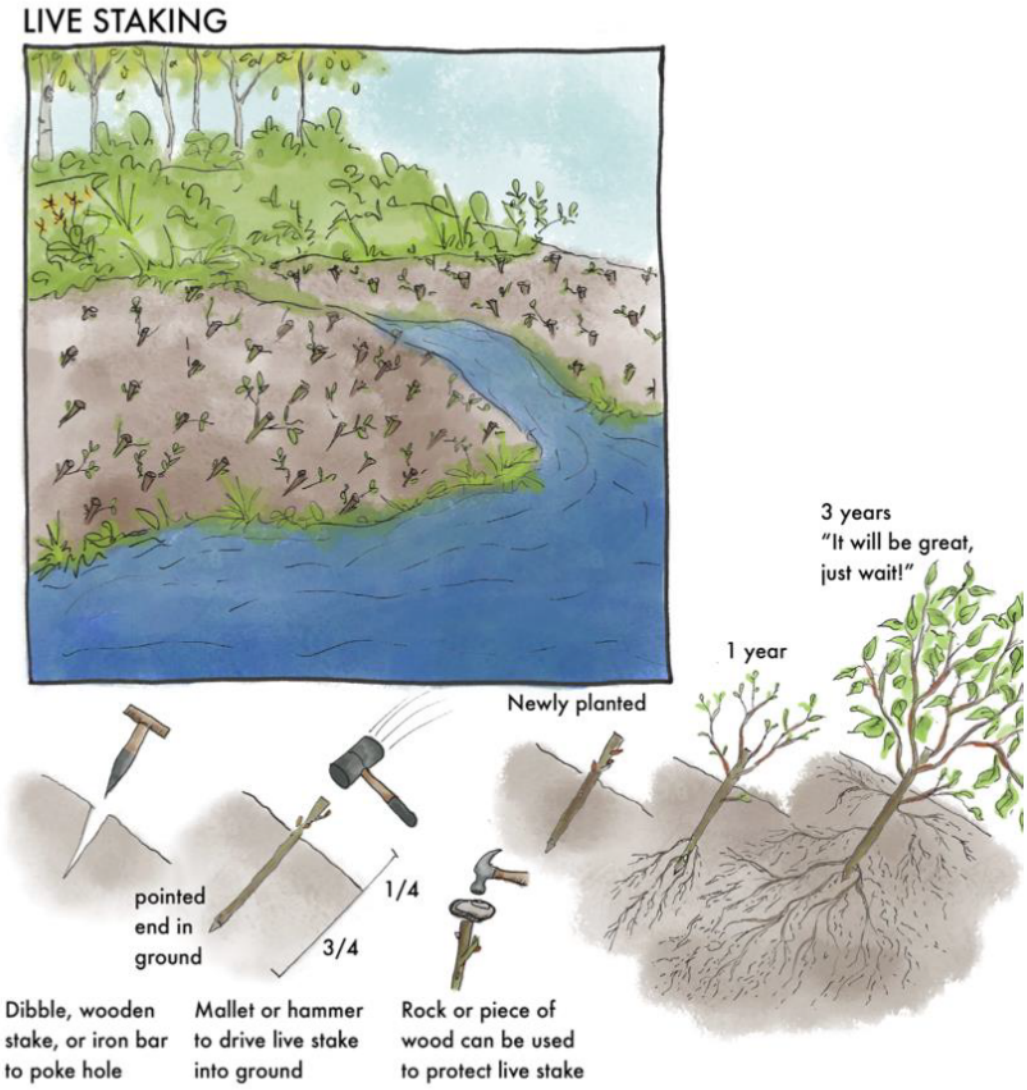


Figure 12. Live staking methods and progression of projected revegetation. From Vermont Department of Environmental Conservation (2025).

Stream barbs (Figure 13) are low dikes or sill-like structures extending from the bank towards the stream in an upstream direction (NRCS, 2007). Stream barbs are useful because they protect large sections of streambank, which requires less disturbance to the riparian habitat during construction (Johnson, 2003). Stream barbs are effective in decreasing erosion rates on site-specific streams (Dave & Mittlestet, 2017, Elhakeem et al., 2017), as well as in meandering channels with varying sinuosity (Karki et al., 2018).



Figure 13. Stream barb in Calapooia River. From Wright et al., (NA).

Given the significant work and resources that are required by river restorations, it seems that a goal of every restoration is to measure success. However, river channel restoration projects typically do not complete long-term monitoring of the restoration area (Buchanan et al., 2014), and instead rely on a brief moment after the restoration is finalized to tell the story of a project's performance. This practice is essentially assuming that restoration success will happen without additional help from restoration managers, of which there is no literature to support this. Restoration project managers cited lack of funds as the reason why more than half of the projects were not monitored after the restoration was completed (Bernhardt et al., 2007). However, as I and other projects (Yang et al., 2018) have demonstrated, using simple, free methods such as LandTrendr change detection analysis is an effective way to determine whether revegetation is occurring as expected. Beyond change detection analysis, on federal lands it is not difficult or time-consuming to inventory an area for invasive species, given I completed that in one day. Using these methods together, even once a year, restoration managers can get a picture of how a

restoration project is progressing after completion. These monitoring methods should not be optional, given that revegetation failure in a river channel restoration is essentially bank stabilization failure and is the only self-sustaining solution for channel stability (Buchanan et al., 2014; Buchanan et al., 2012; Rosgen, 1994).

A new reclamation policy on federal lands could be a solution to minimizing the long-term effects of mining activities in riverine areas. For instance on state lands in Montana, the mined lands must be reclaimed and revegetated (Montana Department of Environmental Quality, 2025). However, these regulations are largely focused on strip or underground mining operations, and has no guidance on dredge tailings or long-term monitoring so state policy should be updated in this context as well.

Implications for Invasive Plant Species

The presence of certain weed species can indicate what stage of succession an ecosystem is in. For example, common mullein typically emerges in an area with recent disturbance and is replaced by other plant species once the disturbed area has recovered (Gross, 1980). The long seed survival of common mullein (~100 years), indicates that new disturbance in the areas that previously had common mullein will result in a resurfacing of that population. The small, single population of common mullein within the Red River Narrows restoration could indicate that the area has recovered from the disturbances associated with restoration and has had little new disturbance in recent times. Other weed species, such as spotted knapweed demonstrate a long residence time and does not require disturbance for invasion (Graham & Johnson, 2004). Life strategies of species such as spotted knapweed, should indicate to a restoration manager that natural succession will not cause these species to disappear over time, and that invasive species treatment(s) is required.

The hydrological effects of invasive species are not commonly studied and are predicted to be more significant with invasive trees due to higher water intake than native trees (Calder & Dye, 2001). This is the case with Russian olive (*Elaeagnus angustifolia* L.) and saltcedar (*Tamarix ramosissima* Ledeb.), which remove large amounts of water from their environment via transpiration (Nagler et al., 2009). There is, however, literature on the hydrological effects of spotted knapweed. Surface runoff under simulated rainfall conditions with spotted knapweed was 56% higher than locations with bunchgrass, while sediment yield was 192% higher (Lacey et al., 1989). Considering the large amounts of spotted knapweed in the Red River Narrows restoration project area (Figure 5), the increase of surface runoff and sediment yield could lead to increased soil erosion and degredation of streambanks, essentially reversing what restoration work was completed.

Wetland ecosystem recovery can be particularly challenging, particularly in the context of invasive species which stalls natural patterns of native plant succession (Aronson & Galatowitsch, 2008). These authors suggest that land managers use active revegetation via planting and seeding over time in wetland areas with low biodiversity, or those areas where the vegetation is lacking native, rarer species. Active revegetation and seeding over time in the Red River Narrows restoration project could assist in mitigating the presence of weed species still present and thriving in the area after 13 years.

Implications for Invasive Plant Treatments

Building upon revegetation strategies, the implementation of controlled colonization offers an additional approach to direct plant succession and suppress invasive species within wetland restoration efforts. To force plant succession towards the preferred climax vegetation, the use of intermediate and late colonizers can be planted simultaneously, known as controlled

colonization (Herron et al., 2001). For instance, planting annual ryegrass and bottlebrush squirreltail (*Elymus elimoides* Raf.) depletes soil nutrients, assisting bluebunch wheatgrass (*Pseudoroegneria spicata* Pursh) in outcompeting spotted knapweed (Herron et al., 2001). Annual ryegrass was likely used as the main restoration species in Red River Narrows, although it has yet to be succeeded by a perennial grass.

Herbicide treatments have played a significant role in managing invasive species within the Red River Narrows restoration area. The Red River Narrows area had herbicide treatments from 2008-2010 and 2012-2018, which consisted of various combinations of metsulfuron methyl, aminopyralid, chlorsulfuron, 2,4-D, clopyralid, and picloram. Treatment efficacy data demonstrate high control of yellow toadflax (85-95%) and a lower control of spotted knapweed (65%) and common mullein (35-65%). Although future herbicide treatment in the Red River Narrows project area would likely be effective, it is not a long-term, low-cost solution. Furthermore, many weed populations in the area are too close to water to be treated by the most effective herbicides, such as clopyralid and picloram for spotted knapweed.

Through the forest's partnership with the Nez Perce Tribe and their biocontrol program, the use of available insects could easily be used and monitored long-term. The most successful biocontrol agents for spotted knapweed are the sulphur knapweed moth (*Agapeta zoegana*), knapweed root weevil (*Cyphocleonus achates*), knapweed gall fly (*Urophora affinis*), and four-barred knapweed gall fly (*Urophora quadrifasciata*) (Story & Piper, 2001). The most appropriate choice for the Red River Narrows project seems to be the sulphur knapweed moth, given that it preferentially attacks older plants and is more successful in combination with competitive plantings of grasses (Story et al., 2000, Mosley et al., 2016).

Grazing of spotted knapweed by sheep is effective before flowering and has reduced densities after three summers (Olson et al., 1997). However, the logistics of allowing goat or sheep grazing on federal land that has removed these types of grazing permits is complicated and likely not feasible in such a small area. In addition, the grazing could lead to further bank instability due to trampling by livestock. Mechanical pulling is an option for certain invasive species, such as spotted knapweed, though stubborn pieces of root left behind can regrow. Given this review of invasive plant treatments and what we know about the species present in the area, it seems that a combination of active revegetation, controlled colonization, and biocontrol are the most effective, long-term, low maintenance, and low cost treatment options.

CHAPTER FIVE

CONCLUSIONS

Using GIS and remote sensing techniques, my case study aimed to use various evaluation methods to assess vegetation changes within the Red River Narrows restoration project area. I accomplished this goal using unsupervised classification to determine overlap between areas dominated by invasive species and those with dredge tailings and exposed substrate, completing a change detection analysis to demonstrate vegetation changes pre- and post-restoration, and through discussion of broader implications for restoration planning and completion, long-term monitoring, invasive species, herbicide treatments, and other factors based on the results.

The results of this study indicate that there seem to be more weed species in areas with dredge tailings and exposed substrate, and that using a change detection analysis is a useful method for land management specialists to determine vegetation changes and recovery in a restoration area. River restoration projects must prioritize revegetation to achieve streambank stability, requiring long-term monitoring to determine restoration success. Further development of remote sensing techniques to get a sense of how a restoration project is progressing may be an essential part of future restorations, considering the lack of long-term monitoring in nearly all ecological restorations.

It should be noted that there was a lack of project information provided by both the Forest Service and the Nez Perce Tribe. As the restoration project began about 20 years ago, it seems crucial that post-assessments should be done and retained to determine the success of any given restoration project. The USDA provides guidance on Stream Visual Assessment Protocol (SVAP) (USDA, 1998) which may have been used but is unknown. It should also be noted that the data regarding the vegetation restoration of the project is speculated upon.

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